IOP Conf. Series: Materials Science and Engineering **966** (2020) 012111 doi:10.1088/1757-899X/966/1/012111

Research of a bi-directional DC-DC converter integrated in electric car power installation

K H Gulyamov[1], B N Sharifov[1], A H Ghulomzoda[2], M Kh Safaraliev[3, 5] and R M Yunusov[3, 4]

[1] Department of Electric drive and Electric machines, Tajik Technical University named after academic M S Osimi, Dushanbe, 734042, Tajikistan
[2] Department of Automated Electrical Systems, Novosibirsk State Technical University, Novosibirsk, 630073, Russia
[3] Ural Power Engineering Institute, Ural Federal University named after the First President of Russia B N Yeltsin, 19, Mira str., Yekaterinburg, 620000, Russia
[4] ABB Ltd., Separate division in Ekaterinburg, Ekaterinburg, 620137, Russia

E-mail: [5] murodbek_03@mail.ru

Abstract. This article presents the results of the simulation study of the bi-directional DC converter, including the time diagrams of the electric vehicle speed, voltage and current changes in various experiments, Also presented are the results of efficiency change and charge level, when using a bi-directional converter as well as without using it. The HFEDC (Highway Fuel Economy Driving Schedule) model was chosen for the simulation of the electric vehicle drive model using units simulating standardized driving cycles and as an algorithm for changing the vehicle's control signal. Studies of the operating modes of the electrical equipment and the electric vehicle with the DC voltage conversion device in the power circuit of the DC source have been carried out by computer simulation in specialized programs for the study of dynamic systems. The simulation model of the reversible DC converter in the electrical power equipment of an electric vehicle was constructed on the basis of mathematical models of the individual elements reflecting their real physical properties. The present solution is the use of two-way DC voltage converters in the power conversion systems of modern electric drives, including the electric propulsion systems of prospective vehicles improves the efficiency of these systems.

1. Introduction

The transport industry, which is one of the main consumers of energy today, due to increased production of vehicles, is faced with problems associated with environmental pollution, due to increasing emissions of greenhouse gases. Against the background of an exacerbation of energy shortages and environmental degradation, automakers are increasingly investing energy and resources in the development of alternative fuel vehicles, mainly the technology for the production of electric vehicles and hybrid vehicles is being developed [1].

Despite the great achievements in the field of electric vehicle manufacturing today, one of the main reasons that impedes the mass production of electric vehicles is the low energy consumption, high weight and high cost of existing traction batteries (TB) used as an energy source.

One of the main components of the electric drive of the electric vehicle is a three-phase traction electric motor generator (EMG) and a power converter (inverter).

The power-driven voltage converter (PDVC) converts the direct voltage of the tractive current source (accumulator battery) into an alternating three-phase voltage required for the operation of the tractive electric machine. Despite the high efficiency of modern traction motors and PDVC, the main transducer circuits and engine windings are subject to significant currents, especially in transient modes, which are frequent for road transport in urban environments.

Given this fact, one solution to the problem of reducing current loads may be the use of a reversible DC/DC converter in a DC circuit. Furthermore, the main function of the reversible DC/DC converter consists in increasing the battery voltage and consequently the voltage at the input of the power inverter, which ultimately leads to a reduction in the currents in the power circuit and in the windings of the traction engine. The latter is related to improvements in the performance of the electric machine and the power conversion equipment, including with regard to the mass dimensions.

Studies have been carried out on combined power sources, battery and supercapacitor in the hybrid car power system using bi-directional DC/DC converters of different topology, which have advantages and disadvantages [7–9].

This article proposes the results of the study of the electric drive of an electric vehicle during the introduction into the structure of said electric power equipment and a reversible DC/DC converter by computer simulation in MATLAB/Simulink. The aim of this solution is to improve the mass dimensions and increase the voltage of the battery without significantly increasing the complexity of its design.

2. Building a simulation model of a DC/DC converter as part of the electric vehicle's energy system

In order to study in more detail, the features of the bi-directional DC/DC converter as part of the power electric equipment of an electric vehicle, a simulation model was created using the software packages of visual modeling MATLAB/Simulink, which today is one of the main tools for the study of dynamic systems.

Using the vehicle parameters shown in table 1, the traction calculation was carried out and the main parameters of the power elements of the electric vehicle were determined [5–6], including the input and output parameters of a bi-directional DC/DC converter installed in the DC power circuit [2–4].

Table 1. Key vehicle parameters for design studies.

Parameters	Symbol	Value
Vehicle Mass, kg	m_a	1748
Vehicle Cross Section, m^2	S_a	2.2
Drag coefficient, p.u.	C_X	0.3
The radius of the wheels of the car, m	r_w	0.323
Transmission efficiency, p.u.	η_t	0.96
Final drive ratio, p.u.	i_{fd}	4.3
Rolling resistance coefficient, p.u.	f	0.014
Road angle, degree	α	0
Air density, kg/m^3	ρ	1.2

Figure 1 shows a simulation model of a power electric equipment system for an electric vehicle, and a bi-directional DC/DC converter in a high-voltage DC power circuit. Designation in the figure: UMEP - unit for measuring electrical parameters; CSCU DC/DC CONV.– control signal conditioning unit bi-directional DC/DC converter; TCS – traction current source; TPI – three phase traction inverter; ADSSU – acceleration and deceleration signal setting unit; SC – speed controller; VCS – vector control system; PMSM – permanent magnet synchronous motor; PS – position sensor; DC/DC CONV. – bi-directional DC/DC converter.

Traction current source is the main source of electrical energy and provides power to all power and on-board consumers. As a traction energy source in this simulation model, a lithium-ion battery with high energy performance is used. Bidirectional DC/DC converter consists of transistor switches VT1,

IOP Conf. Series: Materials Science and Engineering **966** (2020) 012111 doi:10.1088/1757-899X/966/1/012111

VT2 with counter diodes VD1, VD2, inductive coil L and smoothing capacitors C1 and C2. The control signals of the power switches of a bi-directional DC/DC converter are provided by the control signal generating unit (Figure 1).

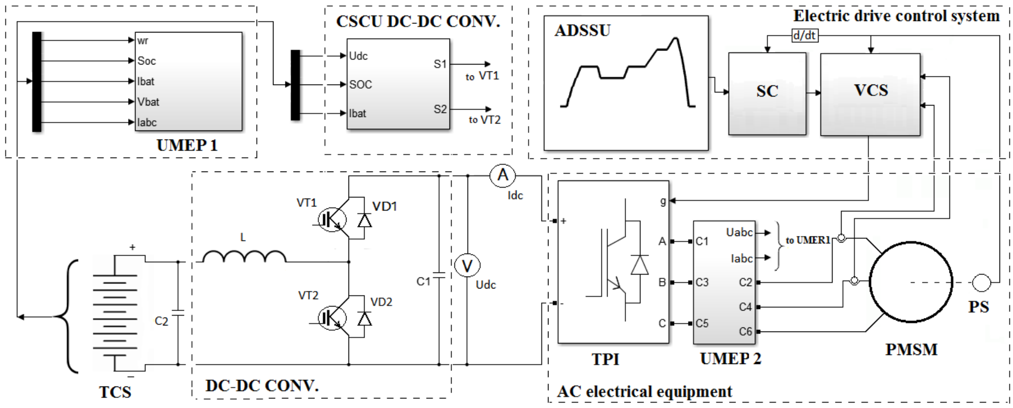

Figure 1. Simulation model of electric vehicle power equipment.

The objective of this DC/DC converter is to increase the voltage of the traction current source to the input of a three-phase traction inverter. In addition, a bidirectional DC/DC converter can operate in a mode of reduction during regenerative braking of the electric drive, when the traction motor operates in the generator mode, while the converter lowers the high-voltage generator voltage rectified by the inverter and provides a charge for the traction current source [3]. The task of a three-phase traction inverter is to convert DC voltage to AC with an adjustable value of the output voltage and its frequency. The control system of the electric drive consists of a unit for setting the acceleration and braking signal characterizing the reaction of the driver, as well as the speed controller and the vector control system, which form the necessary control signal for the power transistor keys of the three-phase traction inverter, providing speed and torque control of the traction motor.

The simulation model of a bi-directional DC/DC converter integrated in a power plant is built on the basis of mathematical models of individual elements that reflect real properties and make up the whole system taking into account the parameters of power electric equipment of an electric vehicle.

It should be noted that the model does not take into account some extreme operating modes of the electric drive, For example, a fully charged battery recovery mode because in this mode the real electric vehicle control system disables the regeneration mode and activates the full-time well braking system thus blocking the return current to the source.

3. The results of the research

In order to confirm the theory of improved traction and improved overall dimensions, as well as the possibility of using a lighter battery, three different experiments were carried out:

1.The electric drive is powered by a battery with a nominal voltage of 400 V DC.

2.The electric drive is powered by a battery with a rated voltage of 650 V DC. The purpose of this experiment is to show the advantage of using a high voltage electric drive.

3.The electric drive is powered by a battery with a nominal voltage of 400 V DC, and a bi-directional constant-voltage converter is used in the high-voltage power circuit, the task of which is to increase the voltage of the battery source from 400 V to 650 V. The purpose of this experiment is to show the advantage of increasing voltage by using a boost converter without significantly complicating and increasing the cost of the battery, which can occur if you follow the second experiment. In order to maximally approximate the experimental characteristics of the simulation model to the real ones, the tests were carried out in a standardized driving cycle of the HFEDC (Highway Fuel Economy Driving Schedule). This movement cycle lasts 765 seconds characterizes the suburban movement.

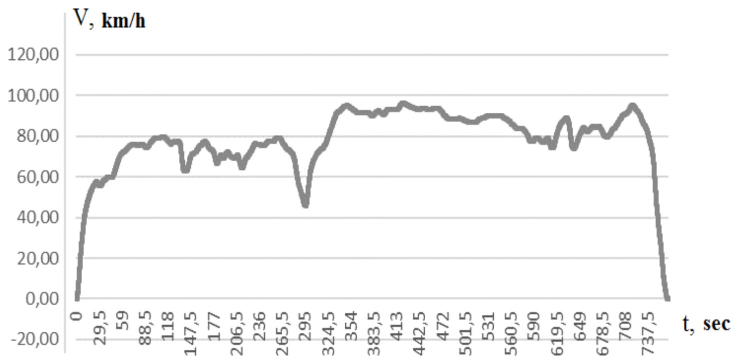

Figure 2. Electric vehicle speed in a cycle.

As can be seen from the presented figure, when conducting three different experiments with different sources, the speed characteristics do not change and comply with the HFEDC standard.

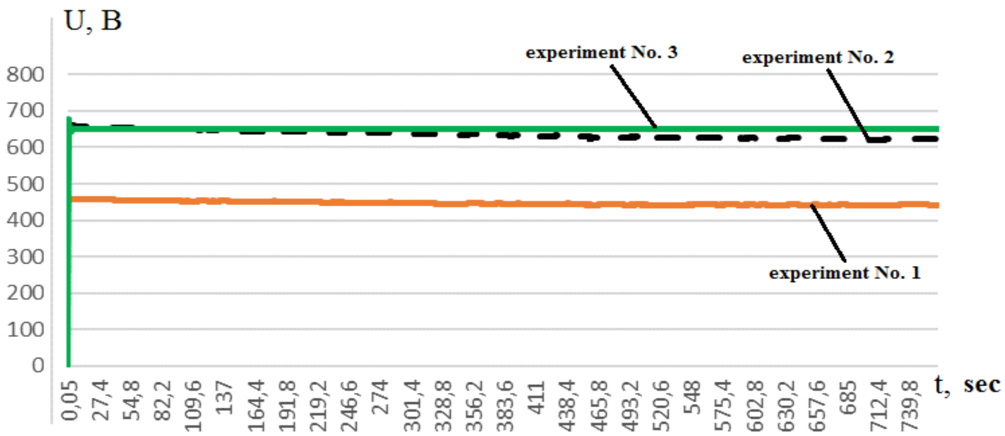

Figure 3. Voltage at the inverter input during three different experiments.

As can be seen from Figure 3 in the third experiment, when a bi-directional DC/DC converter is used, regardless of the decrease in the battery charge level, the voltage remains stable and does not decrease.

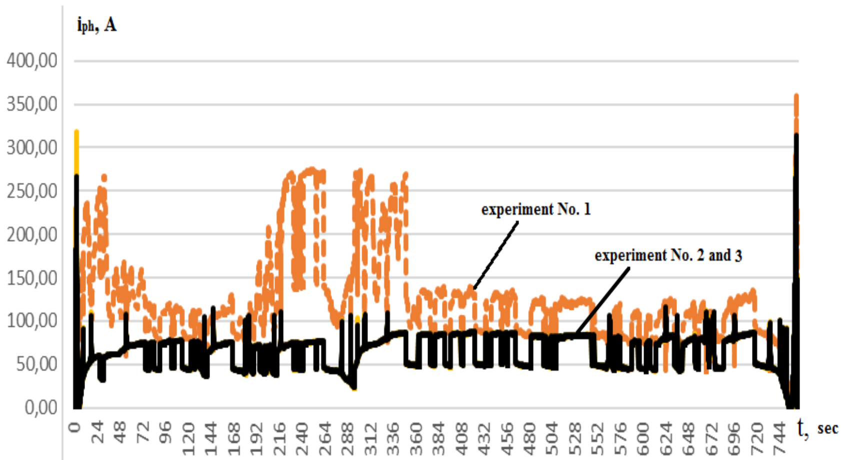

Figure 4. Change in the effective value of the phase current of the motor in three experiments.

This is one of the important advantages of using a bi-directional DC/DC converter in an electric vehicle. Other characteristics show a gradual decrease in voltage with a decrease in the charge level, which will undoubtedly have a negative effect on the traction characteristics of an electric vehicle when the charge level drops to 50% or lower.

As can be seen from Figure 4, the effective value of the active, phase current of the motor in the second and third experiments with a voltage at the input of the inverter 650 V is significantly lower than the first.

With three different experiments shown in Figure 5 shows how the highest efficiency is achieved by using a bi-directional DC/DC converter in the power circuit.

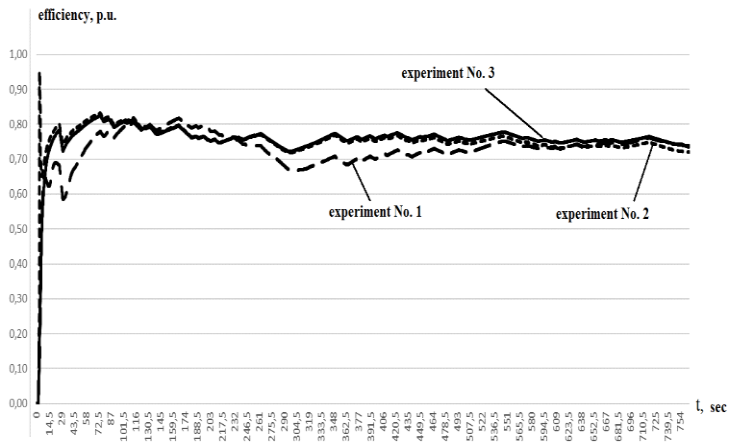

Figure 5. Electric drive efficiency for three different experiments.

Figure 6 shows a diagram of the charge level (SOC) at various values of the supply voltage, from which it follows that the lowest charge consumption in the cycle is achieved when using a bi-directional DC/DC converter.

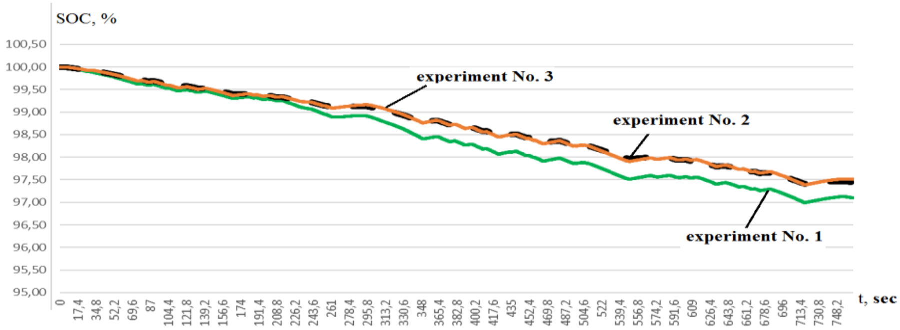

Figure 6. Charge level in three different experiments.

It can be seen from the figure that the charge saving when using a bi-directional DC/DC converter (experiment No. 3) is 0.41%, with a total consumption of 3% for a full cycle. Given the non-linearity of the discharge of the battery, the approximate saving of the charge with the full allowed (DoD = 80 %) energy consumption of the battery will be more than 11%.

Since the load power is the same in different experiments, with increasing supply voltage, the load currents decrease, which is confirmed by the characteristic of Figure 5. A relative increase in efficiency and a decrease in energy consumption occurs due to a decrease in losses with a decrease in load currents, especially in transients, because The electric drive of an electric car, like any car, works primarily in transient modes (frequent acceleration and braking).

It should be noted that the experiments were conducted on two types of electric drives of the same power and different supply voltages.

4. Conclusion

The method proposed in this work for improving the mass dimensions of traction electrical equipment components is most appropriately used in modernizing an already existing electric vehicle when the design change is: The existing storage batteries (SB) and the addition of new elements are difficult and costly. It is also appropriate to use this method when the electric vehicle is small and there is no possibility of mixing a large SB with a weight, but it is necessary to obtain a higher and stabilized voltage source. Also, in industrial trucks with electric traction, which are operated with the possibility of dosage during operation, or in passenger vehicles with a limited SB capacity, which are charged at the end of each line. In this case of increased voltage with PDVC, engines with higher speed and traction performance can be used.

References

[1] Slepcov M A, Dolaberidze G P, Prokopovich A V, Savina T I and Tulupov V D 2006 *Osnovy ehlektricheskogo transporta* (Moscow: Izdatel'skij centr 'Akademiya') p 464

[2] YUtt V E, Sidorov K M and Gulyamov K H 2016 Povyshenie moshchnosti impul'snyh preobrazovatelej postoyannogo napryazheniya s ispol'zovaniem mnogofaznyh struktur *Elektronika i ehlektrooborudovanie transporta* vol **4** pp 13–6

[3] YUtt V E, Sidorov K M, Lohnin K M and Gulyamov K H 2015 Primenenie preobrazovatelej postoyannogo napryazheniya v sostave ehnergeticheskoj ustanovki ehlektricheskogo transportnogo sredstva *Vestnik MADI* vol **4** pp 34–40

[4] Kirill S, Timofey G and Vladimir Y 2015 Method for Calculating the Power Circuit Characteristics of the Isolated DC-DC Converters for Electric and Hybrid Vehicles *Indian Journal of Science and Technology* vol **8** pp 1–8

[5] Chris M, Abdul Masrur M and Wenzhong D 2011 Hybrid Electric Vehicles: *Principles and Applications with Practical Perspectives* (USA) p 485

[6] Rodrigo G V, Joao A and Pecas L 2013 Electric *Vehicle Integration into Modern Power Networks* Springer Science+Business Media (New York) p 325

[7] Hayet S Kh and Ahmed C A 2014 Design of an Hybrid Battery/Super-capacitors Energy Storage System for Hybrid Electric Vehicles *Life Science Journal* vol **11** pp 109–18

[8] Dharam D and Souvik G 2013 Design of a bidirectional dc-dc converter for hybrid electric vehicles (HEV) using Matlab *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* vol **2** pp 2994–3002

[9] CH K P and KP Prasad Rao 2012 Multiphase Bidirectional Flyback Converter Topology for Induction Motor Drive *International Journal of Modern Engineering Research* vol **2** pp 215–8